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METHOD AND SYSTEM FOR CALIBRATING THE SCAN AMPLITUDE OF AN ELECTRON BEAM LITHOGRAPHY INSTRUMENT

TECHNICAL FIELD OF THE INVENTION

The present invention relates to electron beam lithography methods and systems and, more particularly, to a method and system for calibrating the scan amplitude of an electron beam lithography instrument.

RELATED INFORMATION

This application claims priority under 35 U.S.C. §119(e)(1) to provisional application No. 60/076,879 filed on March 5, 1998.

BACKGROUND OF THE INVENTION

The manufacture of electronic integrated circuits relies heavily on the use of image projection techniques to expose resist-coated wafers with light or X-rays. The patterns formed by this exposure determine the various circuit connections and configurations. In any exposure method, accuracy of the projected image is a prime consideration. This accuracy is particularly important in the manufacture of high density random access memories (RAM) in which the yield and ultimately the cost of the components depend heavily on meeting tight exposure placement requirements. With the increasing demand for high performance integrated circuits, the techniques to fabricate semiconductor substrates for microelectronic devices and other purposes have been undergoing continuous development and now include the use of scanning-electron beam lithography systems, both for producing high quality lithographic masks and for direct pattern generation.

Electron beam lithography systems use electron sources that emit electrons at all angles. The electrons are then constrained by the remainder of the system into a narrowly diverging beam. Succeeding lenses then focus the beam into one or more cross-overs before the beam reaches the target. In these systems, electron beams are formed by an electron beam column that, at a minimum, includes an electron source at an object plane and a target at the image plane. Usually the electron beam column includes at least an electron

source at the object plane, one or more lenses, one or more apertures, and the target at the image plane. Columns for electron beam lithographic mask exposure include at least an electron source at the object

5   plane, one or more lenses, one or more apertures, one or more deflectors, a set of beam blankers (which can be driven to stop the beam reaching the target), and a target at the image or mask plane.

In direct pattern generation where the electron

10   beam system creates a pattern directly on a chip covered with resist material, the often complicated and time consuming mask-making process is eliminated. However, one of the key economic considerations in a direct electron beam lithography system for a

15   production environment is the throughput achieved by direct writing relative to a system using a series of masks. This is of particular importance, because direct writing is necessarily a series output process. Hence, time constraints become even more critical in

20   direct pattern generation.

As manufacturers seek ever higher writing speeds, other significant problems also appear. These problems arise often as a result of the relationship among these various parameters. For example, as the writing speed

25   increases, the current density must be increased to maintain the same exposure on the resist. However, higher current densities lead to beam broadening due to electron-electron interactions, thereby deleteriously increasing the line width. Also, a shortened exposure

time further requires a shortened blanking time, since
the rise time of the blanker is closely related to the
accuracy of the exposure of each pixel, and is also a
major concern in avoiding extraneous exposure during

5   blanking. Hence, blanking time in raster scan type
electron beam devices remains one of the key factors
limiting throughput.

Electron beam lithography systems use magnetic
lenses to provide mainly radial acceleration and

10   deceleration in focusing the beam, which is also at
ground potential, at the target. The remainder of the
column is held at ground potential unless more
electrostatic lenses are used to make the electrons
"drift," i.e., experience no electrical acceleration or

15   deceleration through the remainder of the column.

The electron beam position is conventionally
controlled via a technique called raster scanning. In
this method, the electron beam is repeatedly deflected
in a continuous series of ramp deflections and flyback

20   periods similar to a scanning technique used in
televisions. Typically, the electron beam is deflected
as rapidly as possible to minimize the time required to
completely expose a pattern. This increases the
production rate (i.e. throughput) and lowers the unit

25   cost per mask or wafer.

Conventionally, the deflection signal is measured
by its product, i.e., the patterns on the mask or
wafer. Non-ideal pattern placement seen on the mask or
wafer is identified through a series of measurements

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and tests, and appropriate modifications are then made
to the deflection signal to correct these deficiencies.
This method of modifying the performance of the
deflection signal relies heavily on standard procedures
of writing a pattern, processing the mask or wafer, and
then measuring the accuracy of the patterns with
proven, but relatively slow, metrology techniques.
This process may require from one hour for a simple
calibration to several weeks for a full calibration.

Preferably, calibration is performed without
invoking the time-consuming process of writing and
reading actual exposures of masks and wafers. "Real-
time" characterization of electron beam parameters is
achieved by scanning the electron beam at very low
frequencies over a reference grid with known positions.
This technique is well-known in the art and provides
sufficient information to functionally calibrate an
electron beam lithography system.

However, the correlation between these low
frequency measurements and the actual beam writing
deflection signal is not exact. Specifically, the high
frequency writing signal introduces several anomalies
in the electron beam which require further
characterization via extensive pattern writing and
reading. These anomalies include deflection axis
crosstalk, slight deflection axis rotation effects,
gain differences, and scan offsets, all of which vary
as a function of scan frequency.

One important aspect of calibrating scanning
electron beam equipment such as scanning electron
microscopes and raster scan electron beam lithography
machines includes the calibration of the scan

5   amplitude. This is commonly done by reference to the
mechanical movement of the stage on which the sample or
work piece is mounted. By identifying a feature on the
sample and its position within the scan for two
positions of the stage where the difference in stage

10   position is known from some measuring device such as a
laser interferometer the dimensions of the scan can be
determined.

The bandwidth of the video detector chains used
with these instruments is limited due to the low

15   currents used in the electron beam. The scan amplitude
is usually found to be scan frequency dependent.
Reducing the scan rate to match the video bandwidth
available results in calibration error at the higher
scan rates.

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SUMMARY OF THE INVENTION

In light of the above, a need exists for a method and system for calibrating the scan amplitude of an electron beam system such as an electron beam lithography system, that eliminates or reduces deflection axis crosstalk, slight deflection axis rotation effects, gain differences, and scan offsets.

A method for determining the position of a feature within the scan is needed which is effective at the operating frequency of the scan but uses a limited bandwidth video signal.

In accordance with the above-stated needs, the present invention provides a method and system that substantially eliminate or reduce disadvantages and limitations of prior electron beam blanking methods and systems, including the limitation requiring significant bandwidth video signals.

According to one aspect of the invention, there is provided a method for determining the position of a feature within the scan of an electronic beam that is effective at the scan operating frequency and that uses a limited bandwidth video signal. The method includes the steps of considering the reference feature to be an edge over which the video signal changes abruptly from one level to a higher or lower level. In the method, the electron beam is turned on only over a short region of the scan. The method represents the degree of overlap between the beam on portion of the scan and the

higher video level part of the feature as the total video signal accumulated in that scan.

According to another aspect of the present invention, there is provided a method for determining the position of a feature within the scan that is effective at the operating frequency of the scan and that uses a limited bandwidth video signal. The method uses a sample having a video level transition as a reference feature. The method further includes the steps of unblanking the beam for a short period and advancing the unblanked period along the line by a small increment each succeeding period. Sampling the amplifier output by an analog-to-digital converter at a time delay following the unblank period determined by the video amplifier bandwidth is another step of the present invention. The method next involves arranging the successive samples for giving a video profile representative of the video profile of a slow scan with a wide beam. Mathematically processing the representative video profile to yield the position of the video edge with respect to the scan constitutes a final step of the method.

A technical advantage that the present invention provides is the calibration of the scan amplitude of an electron beam system that eliminates or substantially reduces deflection axis crosstalk, slight deflection axis rotation effects, gain differences, and scan offsets. The present method achieves these results by operating effectively at the operating frequency of the

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scan, while at the same time using a limited bandwidth video signal.

Another technical advantage provided by the present invention includes the ability to calibrate the

5   scan amplitude of the scanning electron beam equipment but without the calibration errors that result at the higher scan rates. The present invention achieves this result by cross-correlating the results of two scans. The present method is independent of the exact feature

10   profile of a scanned feature and is resistant to video noise in the profiles. The result yields a method of determining the position of a feature within the scan at the reduced or limited video bandwidth.

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BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description which is to be taken
5 in conjunction with the accompanying drawings in which like reference numerals indicate like features and wherein:

FIGURE 1 shows a side cut-away schematic view of an electron beam lithography system incorporating the
10 teachings of the present invention;

FIGURE 2 illustrates conceptually the deflection function occurring in the present invention;

FIGURE 3 depicts the magnetic focusing of an electron beam from the deflection system of the present
15 invention to a lithographic mask for the purpose of electron beam lithography;

FIGURE 4 shows a conceptual time-line drawing of the scan function that the present invention performs upon scanning a feature to generate a video current
20 pulse;

FIGURE 5 depicts a response obtained from a video amplifier to illustrate the video signal obtained from an amplifier having a limited bandwidth with respect to the frequency content of the input signal;

25 FIGURE 6 illustrates results obtained by simulating the method of the present invention with a beam on pulse of 30 scan units width in 5 scan unit increments across a video edge with a profile represented in the lower trace;

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FIGURE 7 depicts a plot of a cross-correlation function that one embodiment of the present invention may employ, representing the difference between feature positions in the two scans in data points; and

5   FIGURE 8 shows the results of simulating the cross-correlation of the present embodiment in the presence of noise.

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DETAILED DESCRIPTION OF THE INVENTION

Preferred embodiments of the present invention are illustrated in the FIGUREs like numerals being used to refer to like and corresponding parts of the various

5 drawings.

For general understanding of the invention, it is helpful to see the relationship for the blanker to the other elements of an electron beam lithography column. To that end, FIGURE 1 shows a side cut-away schematic

10 view of electron beam lithography system 10 incorporating the teachings of the present invention. Electrons are provided in the column by a cathode which is a thermal field emission electron source 16 much as described in U.S. Patent No. 3,374,386 entitled FIELD

15 EMISSION CATHODE HAVING TUNGSTEN MILLER INDICES 100 PLAIN COATED WITH ZIRCONIUM, HAFNIUM OR MAGNESIUM ON OXYGEN BINDERS, issued to Charbonnier, et al., in 1968. FIGURE 1 shows only half of the column cross-section on the left-hand side of dash line 12. On the right-hand

20 side of dash line 12 appears the electron beam divergence and convergence path enroute to target lithographic mask 14, however, with the lateral dimensions vastly exaggerated. The electron beam appearing in FIGURE 1, therefore, is fairly realistic

25 assuming that the lateral dimension is several thousand times the vertical dimension.

In FIGURE 1, electron beam lithography system 10 includes high reliability thermal field emission tip 16 that emits a beam of electrons that eventually flow in

the direction of lithographic mask 14. From thermal
field emission tip 16, electron beam 18 passes through
magnetic lens 20 which focuses the beam at the center
of electron beam lithography system 10 and directs

5   electron beam 18 through system limiting aperture 22.
Aperture 22 further aligns electron beam 18 with the
optical axis to provide the proper beam shape before
electrons enter blanking device 29.

After passing through system limiting aperture 22,

10   electron beam 18 goes through first magnetic lens 24
and then through second magnetic lens 26 until it
reaches upper plates 28 of electron beam blanking
device 29 of the present invention. Upper deflection
plate set 28 deflects electron beam 18 through blanking

15   aperture 30. From blanking aperture 30, electron beam
18 passes through lower deflection plates 32 of the
present invention, which realigns electronic beam 18
upon its exit from blanking device 29.

FIGURE 2 illustrates conceptually the deflection

20   and beam blanking function that blanking device 29
performs. In FIGURE 2, an equal voltage, V(t), is
driven first positively to upper plate 36 of upper
plate set 28 and then to lower plate 38 of lower plate
set 32. The deflection voltage, V(t), is the applied

25   negatively to upper plate 40 of upper plate set 28 and
lower plate 42 of lower set deflection plate 32.
Blanking aperture 30 is placed midway between plate set
28 and lower plate set 32. This causes electron beam
18 to appear as though it emerges from point 44 of

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aperture 30 which is the axial point located centrally

between the centers of upper deflection plate set 28

and lower deflection plate set 32. The blanking

aperture 30 blanks electron beam 18 as soon as its

5   deflection causes it to fall completely outside the

blanking aperture opening. Until electron beam 18 is

completely blanked, however, it appears, at all

deflection angles, to emerge from blanking device 29 as

though from blanking aperture 30.

10   FIGURE 3 depicts the magnetic focusing of electron

beam 18 from electron beam lithography system 10 of the

present invention to point 46 on lithographic mask.

FIGURE 3 illustrates an object of the present invention

of assuring that the aperture 30 position is optically

15   conjugate with the mask 14 surface so that point

electron 46 on mask 14 remains stationary during

blanking. Stated otherwise, the object at the blanking

aperture is imaged at the mask 14 surface. Therefore,

within the limits of a paraxial approximation of

20   electron optics, any ray which appears to emerge from

the blanking aperture is brought to the same image

point in the mask plane, irrespective of the angle at

which it emerges from lower deflection plate set 32.

U.S. Patent Application Serial No.

25   _____, entitled "ELECTRON BEAM BLANKING

METHOD AND SYSTEM FOR ELECTRON BEAM LITHOGRAPHIC

PROCESSING" filed on March 3, 1998 by G. Plows, et al.,

and assigned to DuPont Photomasks, Inc. (hereinafter

"*Plows*") describes a method and system that

substantially improves blanking stability of an electron beam lithography system even at raster scan speeds of 300 MHZ and higher. The system of *"Plows"* include a first deflection plate pair deflects

5   electrons flowing in the electron beam in the direction of the target lithographic mask. The first deflection plate pair includes a first tapered gap that is formed so that electrons which enter the first tapered gap before the initialization of a blanking voltage

10   experience progressively greater electric field as they pass through the plates for controlling the cumulative deflection as the electrons travel through the first deflection plate pair. A second deflection plate pair further deflects electrons flowing in the electron beam

15   in the direction of the target lithographic mask and includes a second tapered gap for further variably controlling the commutative deflection of the electron beam traveling through the second tapered gap. One or more hybrid integrated circuits provide deflection

20   voltages to the first and second deflection plate pairs for varying the respective degree of electron beam deflection.

The present invention has application in such a system having improved methods of operation for raster

25   scan operations. Accordingly, *Plows* is here expressly incorporated by reference to any and all extent necessary, including to the extent necessary to illustrate the preferred use of the present invention.

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Within the context of the application as described
in Plows, as well as in similar or different equipment
capable of electron beam scanning operations, the
present embodiment includes a method for determining

5   the position of a feature during beam scanning that is
effective at the scan operating frequency. The
preferred embodiment uses a limited bandwidth video
signal that samples to determine a video level
transition as a reference feature. The method includes

10   unblanking the beam for a short period and advancing
the unblanked period along the line by a small
increment in or succeeding sequential periods
following one of more successive scans. The method
further includes sampling the amplifier output by an

15   analog-to-digital converter at a time delay following
the unblank-blank period determined by the video
amplifier bandwidth. The method then includes arranging
the successive samples for giving a video profile
representative of the video profile of a slow scan with

20   a wide beam. Finally, the method includes
mathematically processing the representative video
profile to yield the position of the video edge with
respect to the scan.

A system employing the teachings of the present

25   invention considers the reference feature to be an edge
over which the video signal changes abruptly from one
level to a higher or lower level. The electron beam
turns on only over a short region of the scan during
the calibration. The total video signal accumulated in

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that scan then would represent the degree of overlap
between the beam on portion of the scan and the higher
video level part of the feature.

FIGURE 4 illustrates an important aspect of the
present invention by showing a timing diagram 50 which
illustrates the scan path 52 of the electron beam as
the beam scans over feature 54 to generate the video
current pulse 56. Video current pulse 56 arises from
the overlap of the beam traveling through the
illuminated part 58 of the scan with the high signal
level region to the left of 62 on feature 54. The
signal level rises at 62 to detect edge 60 of feature
54. Thus, rising at 62 to result of the video detector
detecting edge 60. FIGURE 5, in other words, shows the
response obtained from a video amplifier having a slow
frequency response compared with the video current
pulse width. In FIGURE 5, the maximum output from the
associated amplifier occurs at a time delay after the
video current pulse determined by the amplifier
bandwidth and for a time which is long compared to the
incremental resolution of the beam on pulse. If the
video amplifier output is sampled with an analog-to-
digital converter at a fixed delay after the beam on
pulse the converter reading will correspond to the
degree of overlap between beam on pulse and video edge.

The video amplifier will settle back to its
blanked output level before the next scan. If the beam
on pulse is advanced by a small amount along the scan
for succeeding scans, the succession of converter

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values builds a video profile corresponding to that
which would have been obtained with a slow scan and a
bandwidth equal to the beam on pulse width.

    FIGURE 5 illustrates amplifier input and output

5   illustrating the time delay that relates to the present
invention. In particular, in plot 70 appears amplifier
input 72 which is the video input current pulse to the
video amplifier. Output 84 shows the amplifier output
impulse. Thus, video input ranges from 0 to

10 approximately 775 picoamps. Whereas, amplifier output
ranges from 0 to approximately 600 millivolts. FIGURE
6, therefore, provides a graph showing the results of
simulating the method with a beam on pulse of 30 scan
units width stepped in five (5) scan unit increments

15 across a video edge with the profile represented in the
lower trace. The calibration process requires that the
position of a feature within one scan be compared with
that in another scan following a repositioning of the
mechanical stage or a change in some other beam

20 deflection system. This is commonly achieved by
recognizing some attribute of the video profile as
having an absolute position along the scan. Such an
attribute might be the point at which the video signal
is halfway between its minimum and maximum values.

25 Absolute positions so detected are then compared to
give the apparent movement between scans.

    The need to identify a feature attribute and
define absolute positions in the scan may be avoided by
carrying out a cross-correlation between the two scans.

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Cross-correlation may take a number of mathematical forms, one which the preferred embodiment uses is a least-squares correlation approach.

5   In understanding the preferred mathematical form, consider that each scan consists of a number of data points which may be numbered from 1 to N. Let $D1_n$ and $D2_m$ be the nth elements of the first and second scan respectively. The mth element of the cross-correlation function is then:

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$$C_m = \sum_{n=j}^{k} \left(D1_n - D2_{(n+m)} \right)^2$$

15   The value of m for which the cross-correlation is a minimum represents the difference between feature positions in the two scans in data points. Curve fitting to data points either side of the minimum allows for extrapolation of the minimum position to

20   fractions of a data point.

    FIGURE 6 illustrates in graph 80 the video profile collected over successive scans for a video edge profile 84 corresponding to an edge such as edge 62 of device 54 in FIGURE 4. In particular, curve 82 shows

25   sequential data points for 25 successive scans with 5 scan unit increments between scans ranging from 0 to 20. Curve 84 shows the video edge profile ranging from 0 to 1. The horizontal axis of plot 80 represents the

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distance along the scan in arbitrary units that the
detector moves across the edge, such as edge 62 of
FIGURE 4.

In summary, the method of the present invention
5   uses a sample having a black-to-white or white-to-black
video level transition as a reference feature. The
beam is unblank-blanked for a short period during the
scan. The unblank-blanked period is advanced along the
line by a small increment each succeeding scan. At a
10   time delay following the unblank-blank period
determined by the video amplifier bandwidth, the
amplifier output is sampled by an analog-to-digital
converter. The successive samples are arranged to give
a video profile representative of that which would have
15   been obtained from a slow scan with a wide beam.
Mathematical processing of two such successive profiles
yields the amount of feature movement that has taken
place between scans with respect to the scan field.

The present invention provides a novel aspect of
20   stepping the "beam on" pulse. It is common in scanning
electron beam equipment for the timing of beam blanking
signals to be controlled by a digital clock signal such
that a defined number of beam blanking switching
points, or pixels, occur along the scan line. The data
25   point separation and, therefore, the resolution of the
cross-correlation measurement are determined by the
step size by which successive beam on pulses are
advanced along the scan line. This will normally be
determined by the pixel size. The present invention

improves upon this approach by providing a programmable delay which may be set between the blanking pulse generator and the beam blanker itself. This allows the beam on pulse to be advanced along the scan in sub

5   pixel steps that are limited only by the resolution of the programmable blanking delay.

FIGURE 7 shows plot 90 that expresses along the vertical axis ranging from 0 to 8 with the value C_m. Along the horizontal axis is the measurement m ranging

10   from -3m to +3m. Curve 92 begins at cross-correlation value of 7 and decreases to near 0.0 as the value m approaches a minimum value of approximately 0.4. Thereafter, C_m increases to a level of approximately 5.0. Further advantages of using the cross-correlation

15   technique between two scans is that it is independent of the exact feature profile and is resistant to video noise in the profiles.

FIGURE 8 shows the results of simulating the cross correlation approach used in the presence of noise.

20   FIGURE 8 illustrates in plot 100 the average uncertainty of pixels against RMS noise to step height along curve 102. Average accuracy of 0.5 pixels can be obtained with a 10-to-1 signal-to-noise ratio.

Although the invention has been described in

25   detail herein with reference to the illustrative embodiments, it is to be understood that this description is by way of example only and is not to be construed in a limiting sense. It is to be further understood, therefore, that numerous changes in the

details of the embodiments of the invention and additional embodiments of the invention, will be apparent to, and may be made by, persons of ordinary skill in the art having reference to this description.

5 It is contemplated that all such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.